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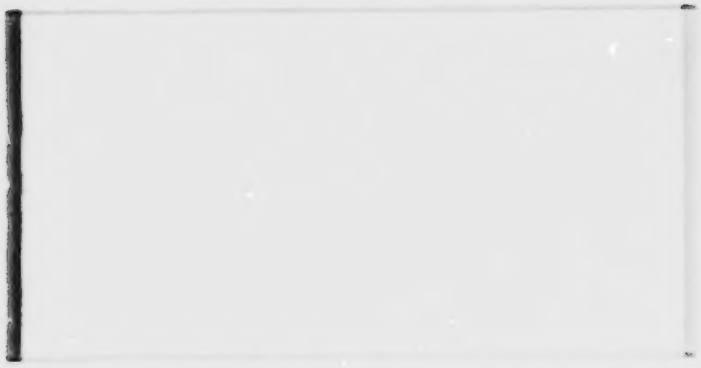

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ACOUSTIC FISH CONTROL DEVICES
DEVELOPMENTAL PHASE

Report No 86-130-K

J. Kowalewski and J.W. Forest
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

Two acoustic devices have been developed for producing underwater sound signals for controlling fish in areas such as water intakes at electric power stations. Tests made in a laboratory tank and in the forebays of three power stations have indicated that both experimental devices produce sound pressures of at least 0.5 kPa (o-p) at 3 m and can elicit a reaction in fish. Further development of both devices is recommended.

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740627-315-492	825.34	May 20, 1986	86-130-K

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EXECUTIVE SUMMARY

ACOUSTIC FISH CONTROL DEVICES - DEVELOPMENTAL PHASE

J.J. Kowalewski and J.W. Forest
Plant Equipment Dynamics Section
Mechanical Research Department

Two experimental acoustic devices, named FISHDRONE and FISHPULSER, have been developed for controlling fish in underwater facilities such as at power station intakes. These experimental devices were developed and tested by the Mechanical Research Department (Plant Equipment Dynamics Section) in cooperation with the Chemical Research Department (Biological Research Section) and the Environmental Studies and Assessment Department.

Preliminary studies of an acoustic and biological nature were made with both devices in a laboratory tank and in the forebays at Lennox TGS, Pickering NGS and Lambton TGS. Descriptions of the devices, acoustical test results, and recommendations for further development are presented in this report. The biological test results are reported separately by Chemical Research.

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ACOUSTIC FISH CONTROL DEVICES - DEVELOPMENTAL PHASE

1.0 INTRODUCTION

As part of a continuing study on fish control, two acoustic devices have been developed for possible application in underwater facilities, such as cooling water intakes at electric power stations. This work was requested by Dr. A. Christie, of OH Design and Development Division, and was conducted in cooperation with the OH Chemical Research Department. The combined project was partly funded by ESEERCO (Empire State Electric Energy Research Corporation).

This report describes the evolution of the two devices, presents some test results, and provides recommendations for further development. The biological test results conducted with these devices are reported separately by Chemical Research. A United States patent application has been filed for both devices.

2.0 BACKGROUND

Previous work with an acoustic source involved the use of a pneumatic popper device to generate high amplitude impulsive sounds/1,2/. Typical signals produced by this device were quite strong, reaching peak pressures of about 10 kPa at 3 m. Most of the acoustic energy occurred at frequencies below 100 Hz and the duration of each impulse, ie time to decay by a factor of ten, was about 100 m sec. Since this type of sound was observed to elicit an avoidance response in some fish, it was deemed worthwhile to explore other means of producing similar but more variable sounds in water for wider applications. Also a more reliable device was needed, since the popper maintenance requirements were too severe. In response to these requirements, a proposal was made for developing a new device for producing the desired sounds based on the principle of resonant sonic vibration/3/.

Because the speed of sound in water is about 4.4 times greater than in air, the wavelength is correspondingly longer. At 100 Hz, one frequency of interest, the wavelength is about 15 m. In order to generate high levels of sound at these low frequencies, the source must be comparable in size to the wavelength,or be capable of transferring energy into the water medium efficiently. The problem is more difficult if it is required to sustain a high level sound, ie longer than 100 m sec, due to the greater impedance in water and, therefore, greater force to be exerted by the sound radiator.

Earlier work involving the excitation of a water-filled tube at sonic frequencies (in this case 700 to 5000 Hz) inspired a possible method to produce such sounds/4,5/. It was observed that when a metallic tube was vibrated at one of its lower order shell modes, high levels of underwater sound pressure could be produced and varied easily in frequency and in time. These findings provided preliminary information for the development of the experimental devices discussed here.

3.0 PILOT STUDY

3.1 Test Facility and Procedure

In order to demonstrate the feasibility of using the sonic resonant vibration method to generate sounds in water, a test was set up in the laboratory as shown in Figure 1.

A sine-wave generator was used to feed a sinusoidal signal through a power amplifier into an electrodynamic shaker having a dynamic rated force of 130 Newtons. The shaker was rigidly connected to drive a pipe which was suspended by a hoist at one end and immersed in a circular water tank at the other end. Both inner and outer surfaces of the pipe section were immersed.

Using the signal generator, the pipe was vibrated through a frequency range from 20 to 500 Hz and the resonant frequencies were identified. The pipe was then driven at one of these resonant frequencies while the sound produced in the tank was analyzed.

In order to examine the capability of producing an impulsive sound, the same pipe was vibrated using single impacts from a hammer with different tip materials.

The input force applied to the pipe by either the shaker or the hammer was arbitrary in these tests. The underwater sound pressure measurements were made using a hydrophone, Celesco LC32, and an FFT analyzer, NSC 446.

3.2 Results from Pilot Study

An example of the sound waveforms and spectra produced by the pipe in water by each of the two methods of excitation are shown in Figures 2 (a),(b) and 3(a),(b).

With the shaker vibrating at 107.5 Hz, one of the resonances of the pipe-shaker system, a steady sound was generated in the tank which could be maintained for over one minute. The amplitude in this case, with the shaker set arbitrarily at less than maximum output, was about 0.04 kPa (o-p), Figure 2(a).

A second test was made using a hammer with a soft tip striking the pipe. The sound produced was a rapid rise in pressure up to a single peak followed by an exponential decay or ring-down. The duration and amplitude of the sound from this arbitrary single impact was in the order of 250 ms and 1.0 kPa (o-p) respectively, Figure 2(b).

The amplitude of sound measured in these experiments was not absolute because of the reverberant and near-field acoustical conditions existing in the test tank.

The frequency spectra produced by each method of excitation were similar only at the fundamental frequency of this test system, ie 107.5 Hz, Figures 3(a) and (b). With steady excitation from the shaker, the sound spectrum comprised a fundamental and several harmonics. Other resonant frequencies and their harmonics were easily produced by simply tuning the sinewave generator to other frequencies. An example is shown in Figure 4.

With the hammer, however,the sound spectrum was relatively complex and could be varied only by using different hammer tip materials (Figure 3b).

Brief tests made using an aluminum pipe and a 45 gallon steel drum gave further indication that high amplitude, low frequency sounds could be generated in water by this method.

3.3 Findings from Pilot Study

Based on the above laboratory experiments, it was found that:

3.3.1 The steady excitation method had the potential of producing long exposure sound having substantial frequency control flexibility.

3.3.2 The impact excitation method had the potential of producing high amplitude, impulsive sound.

3.3.3 The efficiency of the acoustic radiator for transferring sound energy into water had to be optimized, regardless of the method of excitation used, in order to achieve sounds in water that could elicit a behavioural response in fish.

4.0 EXPERIMENTAL STUDY

The objective here was to assemble two prototype devices for conducting tests on fish in a 8 x 8 x 2 m deep tank and later at a power plant forebay. The first device, designated FISHDRONE, was

for producing steady, intermittent sounds. The second device, designated FISHPULSER (also referred to as "HAMMER") was for producing impulsive, repetitive sounds.

Based on the findings from the pilot study, the initial design approach was to utilize 45 gallon steel drums for building both devices. The drum served as a convenient, waterproof, enclosure for the driving mechanism and as an underwater acoustic radiator.

A list of the experimental units tested and their mechanical performance is shown in Appendix I.

4.1 Description of FISHDRONE Units No D3 and D4

The general arrangement of this device is shown in Figure 5. The electronic components were essentially those used in the pilot study.

A programmable sinewave generator, HP 3314A, fed a discrete frequency signal to a power amplifier (B&K 2707). The output from the amplifier was fed through a 10 m waterproof cable to an electrodynamic shaker (B&K 4801 and 4812) mounted inside the steel drum enclosure. The shaker head was attached to mechanically drive the "front plate", ie drum bottom, as shown in Figure 6.

When immersed in water this enclosure was pressurized with compressed air to balance the static deflection of the front plate due to hydrostatic pressure at the given depth. A temperature gauge was installed for monitoring the shaker temperature during extended testing. Also a marine float switch was installed to indicate any ingress of water. These probes were needed to help prevent possible damage of the shaker during experiments. Auxiliary cooling for the shaker was provided by circulating water through a heat exchanger inside the enclosure using a marine bilge pump (not shown in Figure 6).

The sealed enclosure was weighted to overcome its buoyant force and was suspended at its test position by a hoist. All cables and air supply tube were fed through a waterproof connection in the enclosure and inside a 10 m long flexible hose leading to the power control equipment. This equipment and all instrumentation was located at a nearby work station.

4.2 Laboratory Tests - FISHDRONE D2

The objective was to verify the operation and measure the acoustical characteristics of this prototype unit. The test tank was 8x8x2 m deep with hard walls and floor and was, therefore, acoustically reverberant. Measurements were made with the same instrumentation as in the pilot study (Section 3.1).

Figure 7 shows a typical sound field generated by the FISHDRONE D2 operating at a 377 Hz resonance at maximum power of the shaker (130 N, Ling shaker). The sound pressure varied spacially in the tank, due to reverberation, ranging from 0.1 to 0.4 kPa (o-p). This result confirmed that any observations on fish reaction to sound in the tank would have to account for reverberation effects.

Figure 8 illustrates three of the resonant frequency spectra produced separately by unit D2. It is important to note that the fundamental (driving) frequency was not always dominant over the harmonics as shown in Figure 8(b). The presence of harmonics, therefore, may be a significant factor influencing fish behaviour.

It was also observed that, in order to reach maximum sound pressure, the shaker had to operate continuously for at least two seconds. This was the time required to establish full amplitude resonance in water.

4.3 Lennox Forebay Tests - FISHDRONE D3

The objective was to determine if fish would react to sounds produced by this device, and to assess the overall sound pressures being generated in the forebay situation. This unit was similar to that tested in the laboratory except that a stronger shaker (445 N rated dynamic force) was used.

Figure 9 illustrates the mode of operation selected for all tests with unit D3, ie 3 sec bursts per 4 sec cycle. The driving frequencies were 64, 99 and 153 Hz. Depth of the device was 2.0 m.

Figure 10 shows the overall sound pressure measured over 0 to 10 kHz at distances up to 12 m from the front plate and at three depths (1.0, 2.0, and 3.0 m). At the 3 m "reference" distances the sound pressure in all tests ranged from 0.45 to 1.20 kPa (o-p). The sound pressure dropped inversely with distance squared but levelled out between 6 to 12 m. In fact, at the 6 m location the sound pressure was relatively low in all cases. This pattern suggests a standing wave condition which was likely caused by reflections from the walls and bottom of the forebay.

Variations in pressure with depth were significant, particularly within 6 m of the unit. Typically, sound pressure increased with depth from 1 m to 3 m, except in some situations where it varied. See, for example, Figures 10(b) and (c).

If the sound pressure gradient has an effect on the behaviour of some fish species, then the results in Figure 10 suggest that the sound field in a semi-confined reverberant channel such as the Lennox forebay may cause problems in interpreting fish movement correctly. For example, the fish may move to a location closer to the source, when in fact it is an area of lower sound pressure level.

4.4 Lambton TGS Forebay Tests - FISHDRONE D4

The objective of these tests was to observe if fish in the forebay would react to sounds produced by this unit. This device was essentially the same as Unit D3 tested at Lennox except that a new (unused) drum enclosure replaced the old one. Again the biological observations are reported separately.

Resonant frequencies generated by Unit D4 were 40, 105 and 164 Hz. These were somewhat different from those generated by Unit D3 at Lennox. This change could be expected due to differences in drums, device assembly, and water temperature.

The operating mode was again in 3 sec bursts per 4 sec cycle. Overall sound pressure at about 1 m depth and 1 m from the front plate ranged between 0.3 and 1.2 kPa (o-p).

4.5 Description of FISHPULSER Units No P2 to P7

Figure 11 shows the initial version of the impact sound source, Unit P2, that was used for experiments in the laboratory tank. Briefly, a steel rod was suspended by three springs inside an empty drum. The rod was used as a hammer to strike a reinforcing plate on the bottom face of the drum. The hammer could be loaded against the force of the springs and released to impact the plate by means of a latch and trigger mechanism which was operated manually by cables.

Subsequent improvement of this device, Units P3 to P7, was to provide automatic, controlled operation as shown in Figure 12. Again a 45 gallon drum with strike plate was used as a sound radiator and waterproof enclosure. The hammer, in this case, was mounted on a bar which served to guide it against a spring and the strike plate.

Power to "load" the hammer against the spring was supplied by a 115 Vac, 1/4 HP motor with integral speed reducer. The motor powered a sprocket and chain drive mechanism that latched onto the hammer to displace it against the spring thus compressing it. At the end of this travel, about 40 cm, the latch released the hammer causing it to impact upon the strike plate. When immersed, the energy from this impact would transfer through the enclosure front plate directly into the water producing an impulsive sound signal. The repetition rate of impacts was about 21 impacts/min. The impact force was controlled by using springs of various stiffnesses. The spring rates used ranged from 0.35 to 2.10 N/mm (2.0 lb/in to 12.0 lb/in).

As with the FISHDRONE, these experimental devices were equipped with a float switch, temperature gauge, and pressurized air (Section 4.1). Ballast weights were installed inside the sealed

enclosure which was suspended at its test position by a hoist. Again, all cables and air supply were fed through a waterproof connection in the enclosure and inside a 10 m long flexible hose leading to a power supply and instrumentation on shore or on a boat.

4.6 Laboratory Test - FISHPULSER P2

The purpose was to observe the reaction of individual fish in the 8x8x2 m deep tank and to obtain basic data in preparation for subsequent field tests.

As was found earlier, the sound pressure distribution in the tank was complicated by reverberation which caused large variations in measured pressures. Although unit P2 was found too laborious to operate (manually) it demonstrated that this approach was feasible for generating the desired characteristics of the impulsive sounds to be used as a fish deterrent.

4.7 Lennox Forebay Tests - FISHPULSER P3, P4, and P7

Again the objective was to determine reaction of fish to impulsive sounds, including a mortality check, and to assess the acoustic characteristics of the sounds generated by this device in the Lennox forebay situation.

Figure 13 shows typical histories (at two display ranges) of the instantaneous sound pressure at a repetition rate of 21 impacts/min, ie a period of 2.85 sec. The higher peak amplitude shown in the 1000 Hz display range, Figure 13(b), indicates that much of the acoustic energy was produced at higher frequencies. This was confirmed by frequency spectrum analysis obtained from averaging twenty separate impulses, as shown in Figure 14. It is evident from this example that a broader range of frequencies were present with this device than with the FISHDRONE or the POPPER which may be an important factor in producing the desired fish response.

The duration of this signal (time to decay by a factor of ten) was of the same order of magnitude as the POPPER, about 200 msec.

Figure 15 shows the overall sound pressure measured over a frequency of 0 to 10 kHz at distances up to 12 m from the front plate of Unit P4, at three water depths, and with three separate spring rates. Using the 3 m distance as the "reference" location the effect of spring rate on the overall sound pressure from Unit P4 was as follows:

SPRING RATE		OVERALL SOUND PRESSURE (mean of three depths)	
N/mm	lb/in	kPa (o-p)	psi (o-p)
0.35	2.0	0.6	0.087
1.05	6.0	1.4	0.203
1.40	8.0	1.9	0.275

The sound pressure dropped inversely with distance squared, as expected, without significant deviation from theoretical attenuation. Variations of sound pressure at the three depths were significant, generally increasing with depth.

It appears that the sound field produced by the FISHPULSER has a regular pressure gradient in the horizontal plane, which may be significant in producing the desired fish response.

4.8 Pickering NGS and Lambton TGS Forebay Tests - FISHPULSER P5, P6 AND P7

Again the objective at these stations was to test the reaction of fish to sounds produced by these units. These observations are reported separately.

The devices used here were essentially the same as those described in Section 4.5 with a spring rated at 1.40 N/mm. It was found that due to prolonged use during these tests,that the drum front plate eventually cracked. This necessitated replacing the drum as indicated in the summary, Appendix I.

5.0 CONCLUSIONS

The following conclusions are drawn from this study:

5.1 Based on the pilot study, two experimental devices were developed for generating sounds in water that have the potential for eliciting a behavioural response in fish. The first device, named FISHDRONE, produces steady, intermittent sound at selectable discrete frequencies. The second unit, named FISHPULSER produces impulsive sound over a broad band of frequencies by exciting many structural natural modes of vibration.

5.2 Tests made in a laboratory tank and in the forebay of a power station indicated that both experimental devices are capable of producing sound pressures in water of at least 0.5 kPa (o-p), (0.07 psi) at 3 m away. Both devices can be designed to generate greater output.

5.3 In a confined water facility, such as the laboratory tank or the Lennox forebay test site, the sound pressure field produced by both devices was influenced by standing waves caused by reverberation. This acoustical condition may cause difficulty in correctly interpreting fish movement within such fields.

5.4 The FISHDRONE offered a wide range of temporal and spectral signal characteristics from the same unit. The signals tested in this study had one sequence only, ie 3 sec burst per 4 sec cycle, and four driving frequencies, 27, 64, 99 and 153 Hz.

The greater flexibility of this device may make it attractive as an underwater acoustic source for various uses, such as attraction as well as repulsion.

5.5 The mechanical integrity of both experimental devices was suitable for the brief tests that were conducted. For prolonged operation these devices will require more durable enclosures and other refinements.

6.0 RECOMMENDATIONS

Based on the findings in this study, the following recommendations are made:

6.1 Develop further both the FISHDRONE and FISHPULSER ("HAMMER") to provide more robust enclosures and driving mechanism for prolonged operation. Using the modal analysis technique, design the enclosure system to produce the desired frequency sound at maximum energy transfer efficiency.

The use of other driving mechanisms, such as a magnetostrictive vibratory source for the FISHDRONE, should be explored. Also the possible advantages of orienting the FISHPULSER to strike vertically downwards, thereby using gravitation force, should be explored.

6.2 In order to describe the sounds due to the experimental devices developed and to understand fish reaction to them, the following parameters should be included in future tests: repetition rate, peak amplitude, rise time, duration, waveform, and crest factor.

6.3 Future development of these devices should determine the directional radiation pattern of each device, optimum water depth, and area of influence on fish due to a multiple array of devices.

7.0 ACKNOWLEDGEMENTS

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APPENDIX I

Summary of Experimental Acoustic Devices Tested
Developmental Phase

Device	Special Features	Tests	Developmental Considerations
FISHDRONE			
D2	Used drum, 130 N shaker	Lab tank	Seal leaked
D3	Used drum, 445 N shaker, clamped seal	Lennox GS	Front plate cracked
D4	New drum, 445 N shaker, clamped seal	Lambton TGS	Seal leaked
FISHPULSER			
P2	Used drum triple spring, manual	Lab tank	Laborious to operate
P3	Used drum, linear ball bearing, single spring	Lennox GS	Bearing failed
P4	Used drum, oilite bushing, single spring, 1.05, 1.40, & 2.10 N/mm interchangeably	Lennox GS	No failures
P5	As P4 with 1.40 N/mm spring	Pickering NGS	Front plate cracked
P6	As P5, replaced with used drum	Pickering NGS	Front plate cracked
P7	As P6, replaced with new drum	Lennox GS Lambton TGS	No failurs Seal leaked

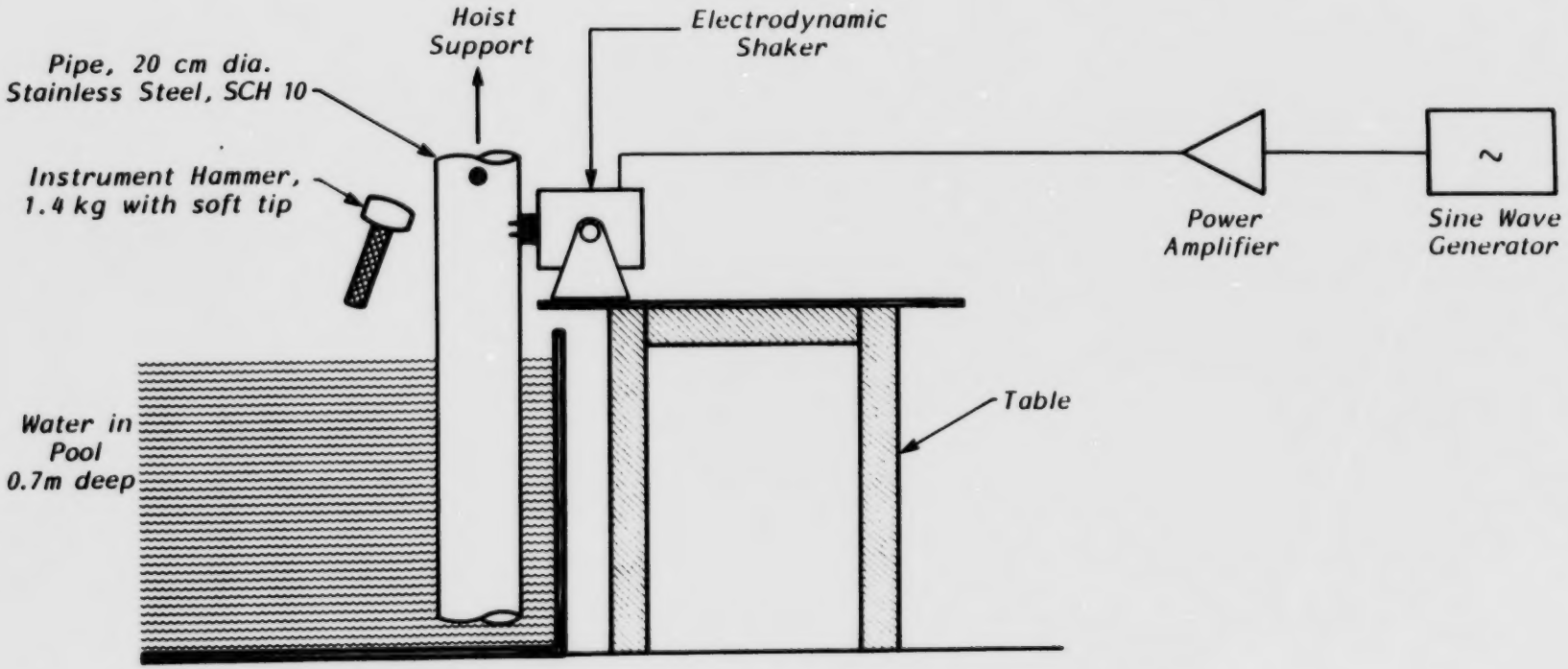


FIGURE 1

TEST ARRANGEMENT FOR FEASIBILITY STUDY

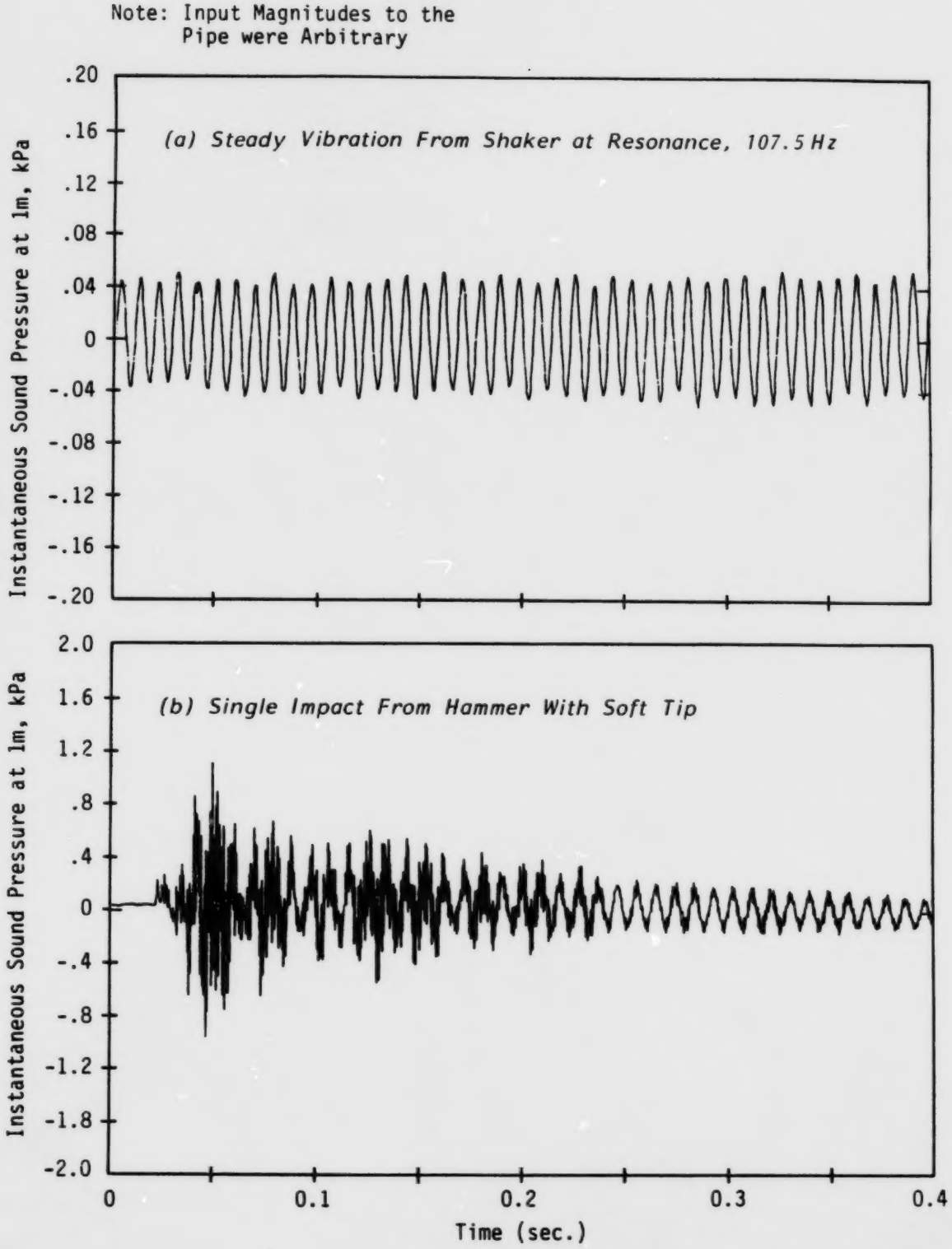


FIGURE 2

TIME HISTORIES OF SOUNDS PRODUCED BY THE 20cm DIA. PIPE EXCITED BY (A) SHAKER AND (B) HAMMER

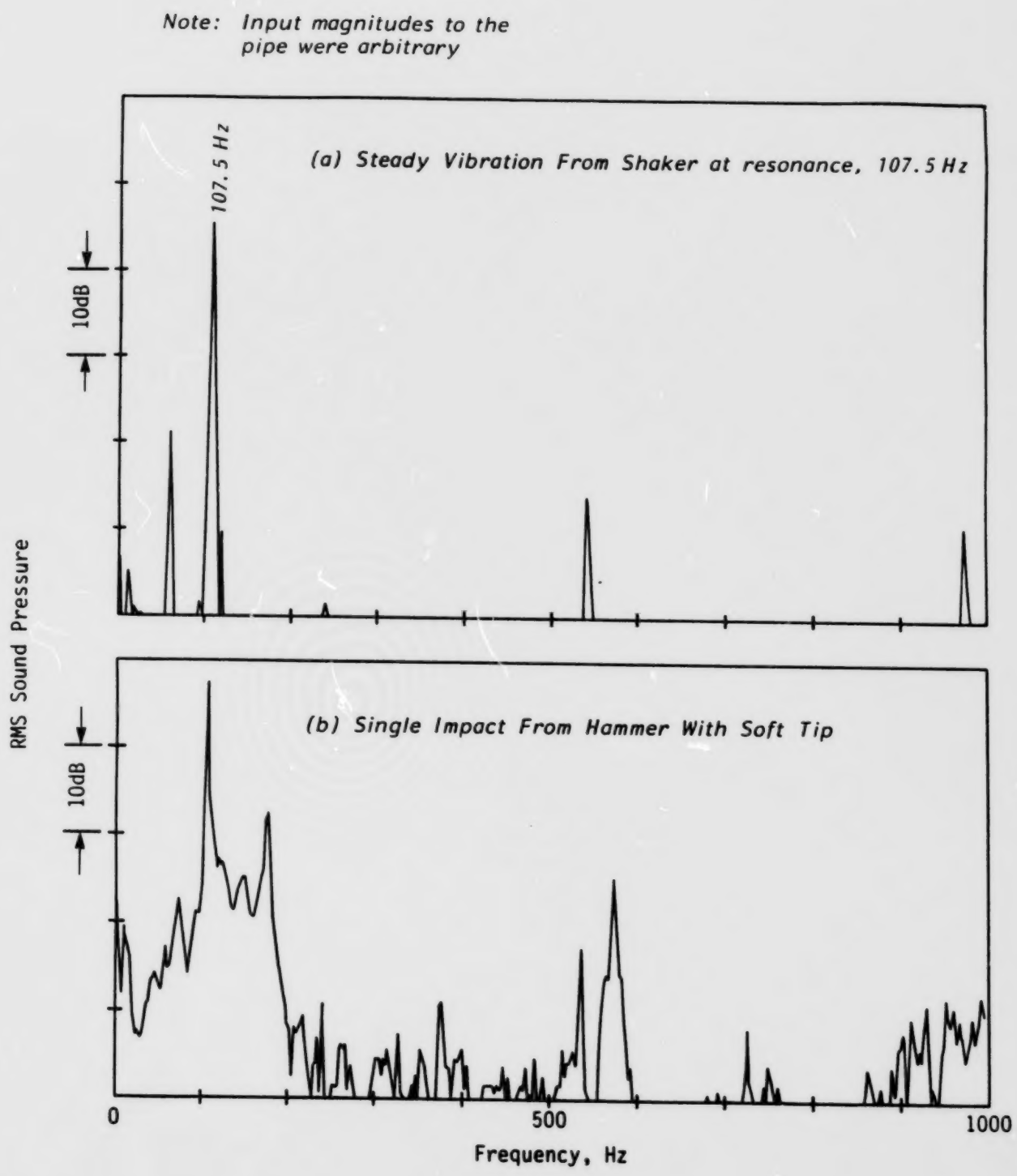


FIGURE 3

FREQUENCY SPECTRA OF SOUNDS PRODUCED BY THE 20cm DIA. PIPE EXCITED BY (A) SHAKER AND (B) HAMMER

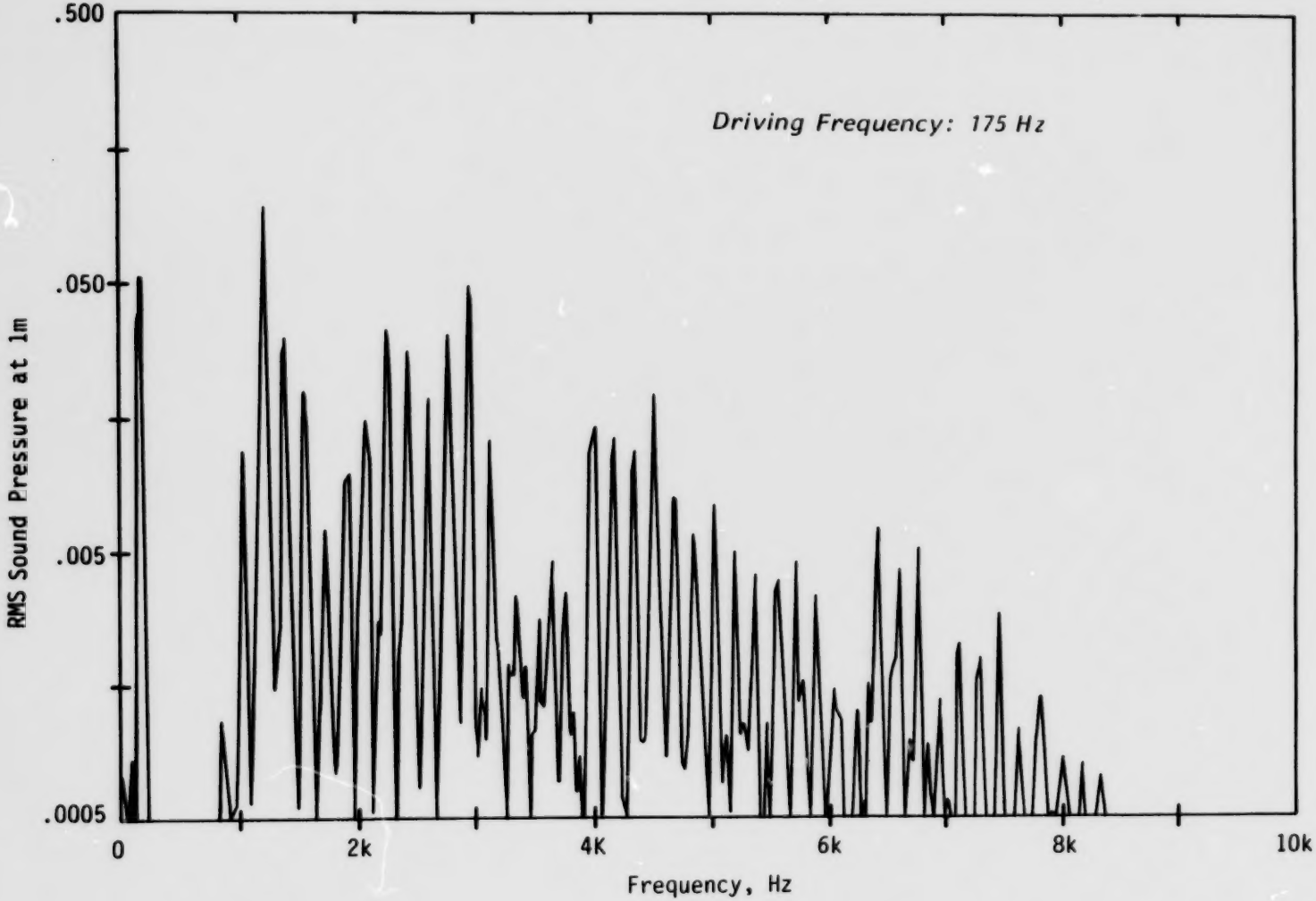


FIGURE 4

EXAMPLE OF STEADY UNDERWATER SOUND PRODUCED BY RESONATING PIPE
(STAINLESS STEEL PIPE, SCH 10, 20cm DIA. EXCITED BY ELECTRODYNAMIC SHAKER)

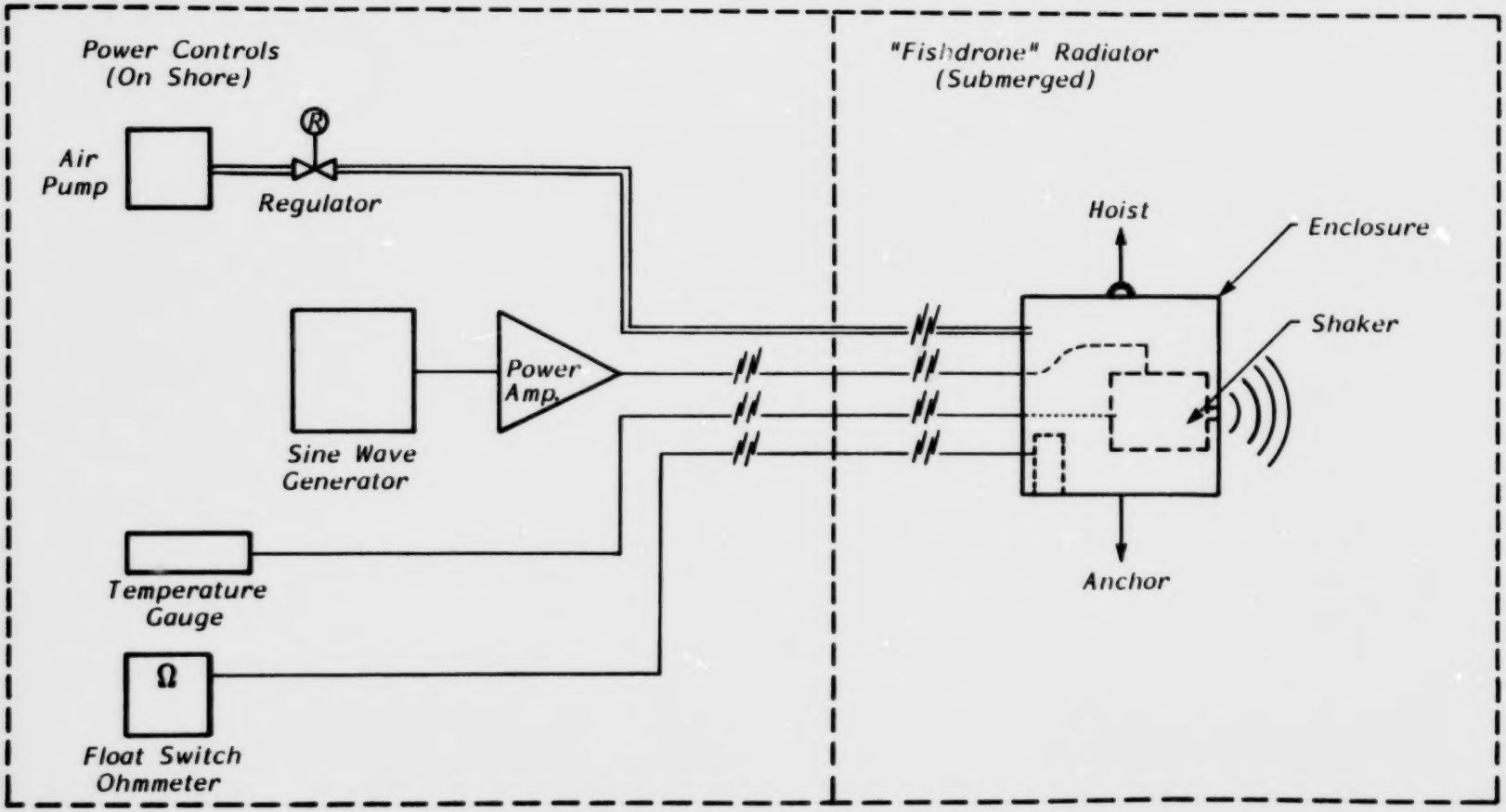
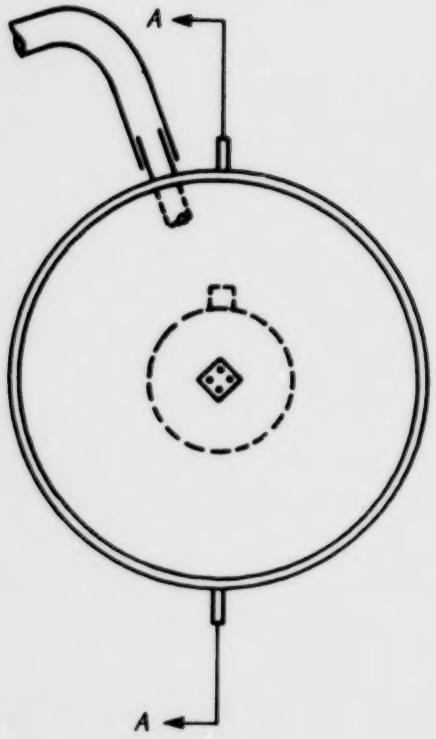


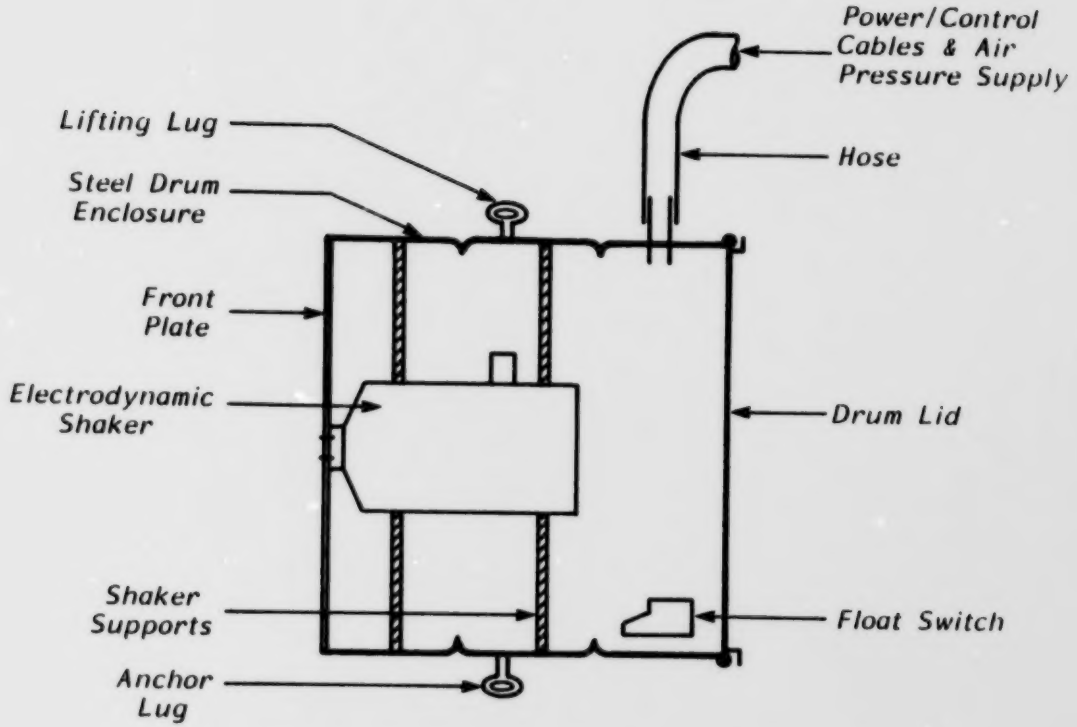
FIGURE 5

GENERAL ARRANGEMENT OF "FISHDRONE"
EXPERIMENTAL UNITS NO. D3 & D4

170785 RD



Front View



Section A-A

FIGURE 6

SCHEMATIC OF "FISHDRONE" NO.D3 & D4
- EXPERIMENTAL UNIT USED IN LABORATORY AND FIELD TESTS

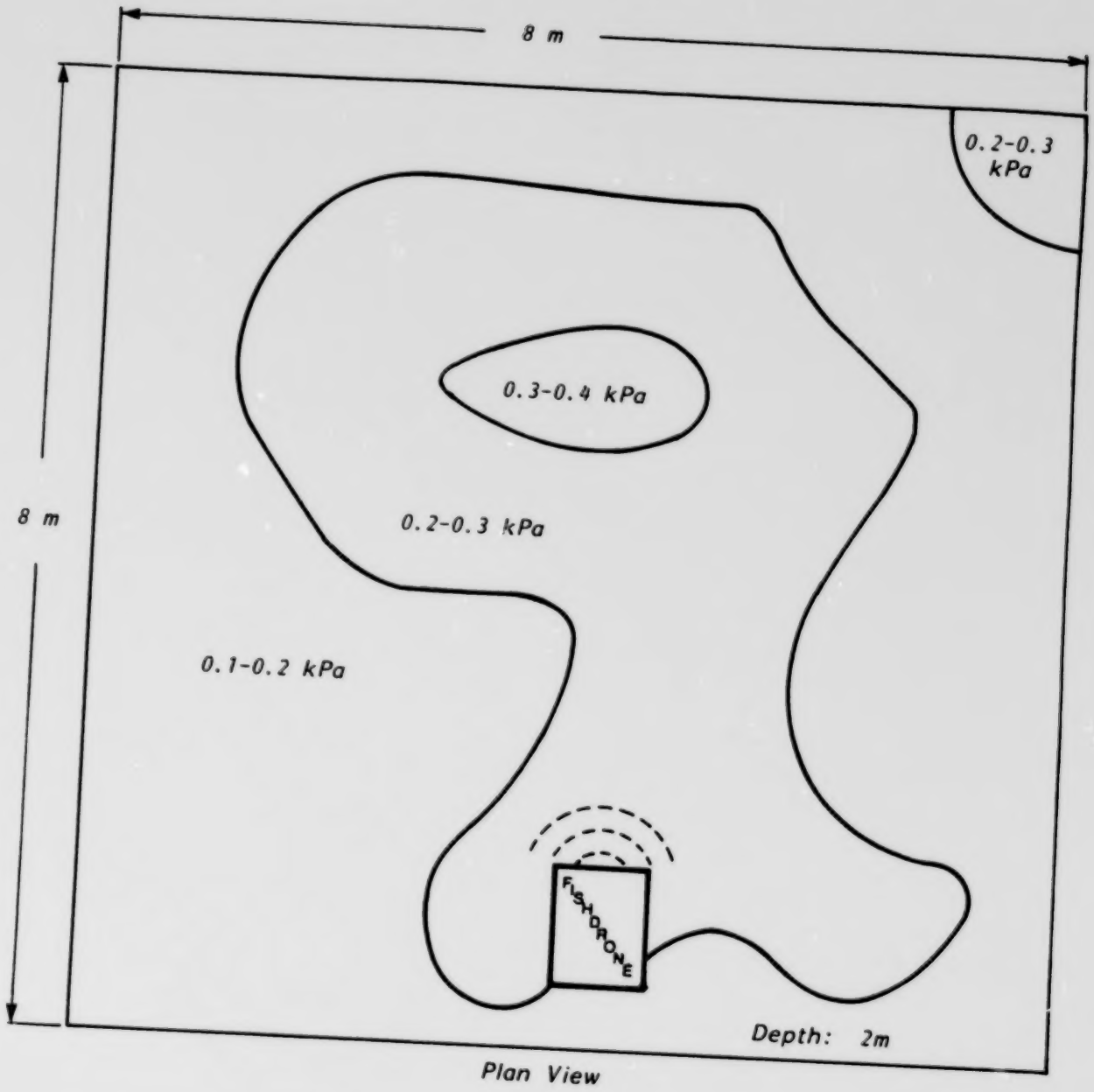


FIGURE 7
SOUND FIELD GENERATED BY "FISHDRONE" DRIVEN AT 377 Hz IN REVERBERANT WATERFILLED TANK

171039 RD

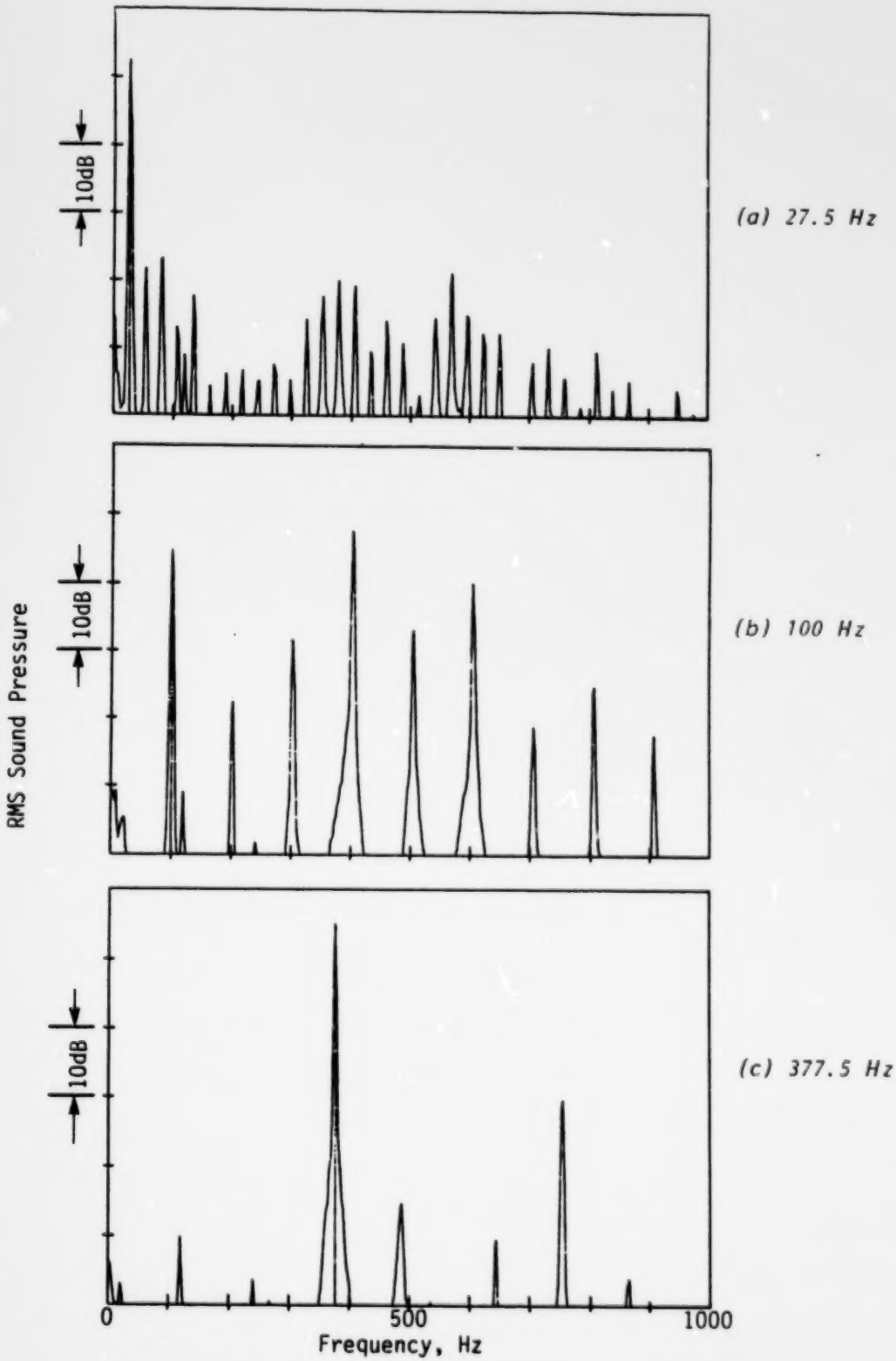


FIGURE 8

TYPICAL UNDERWATER SOUND SPECTRA FROM FISHDRONE NO. D2 DRIVEN AT THREE RESONANT FREQUENCIES

170789 RD

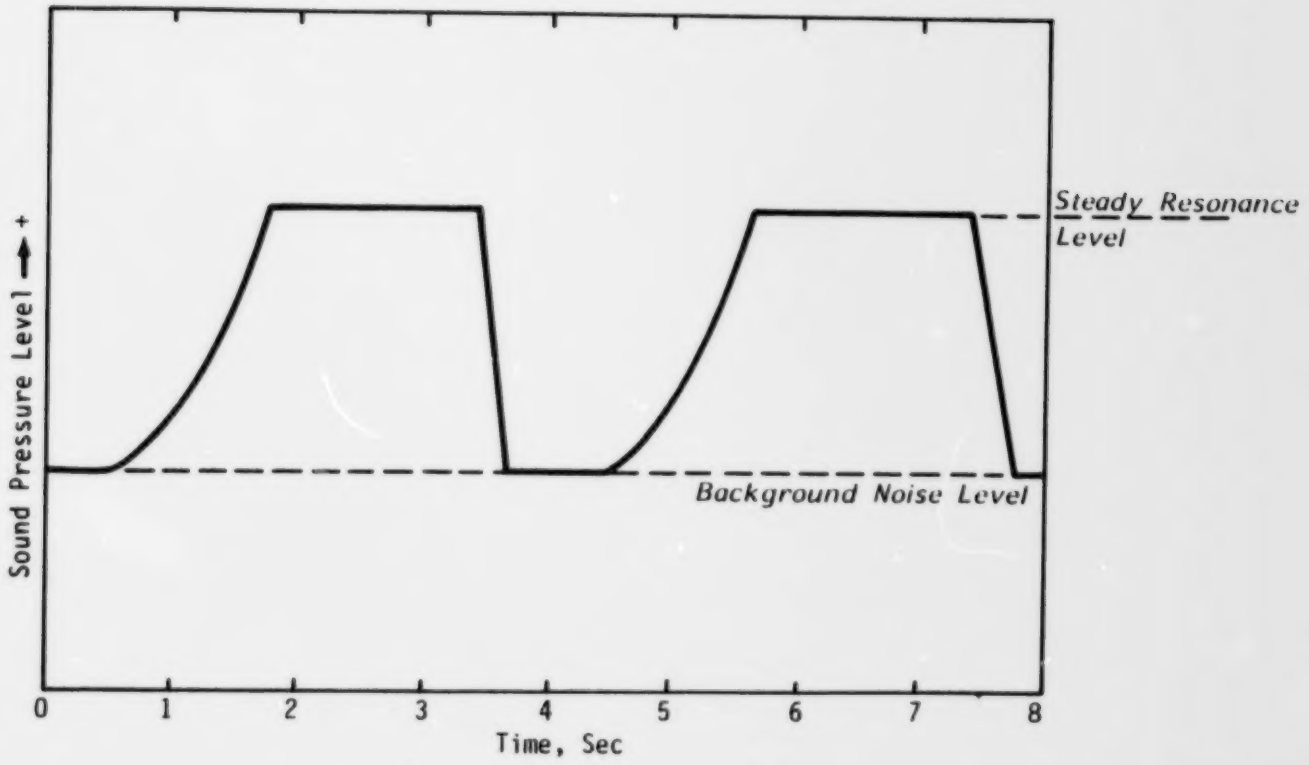
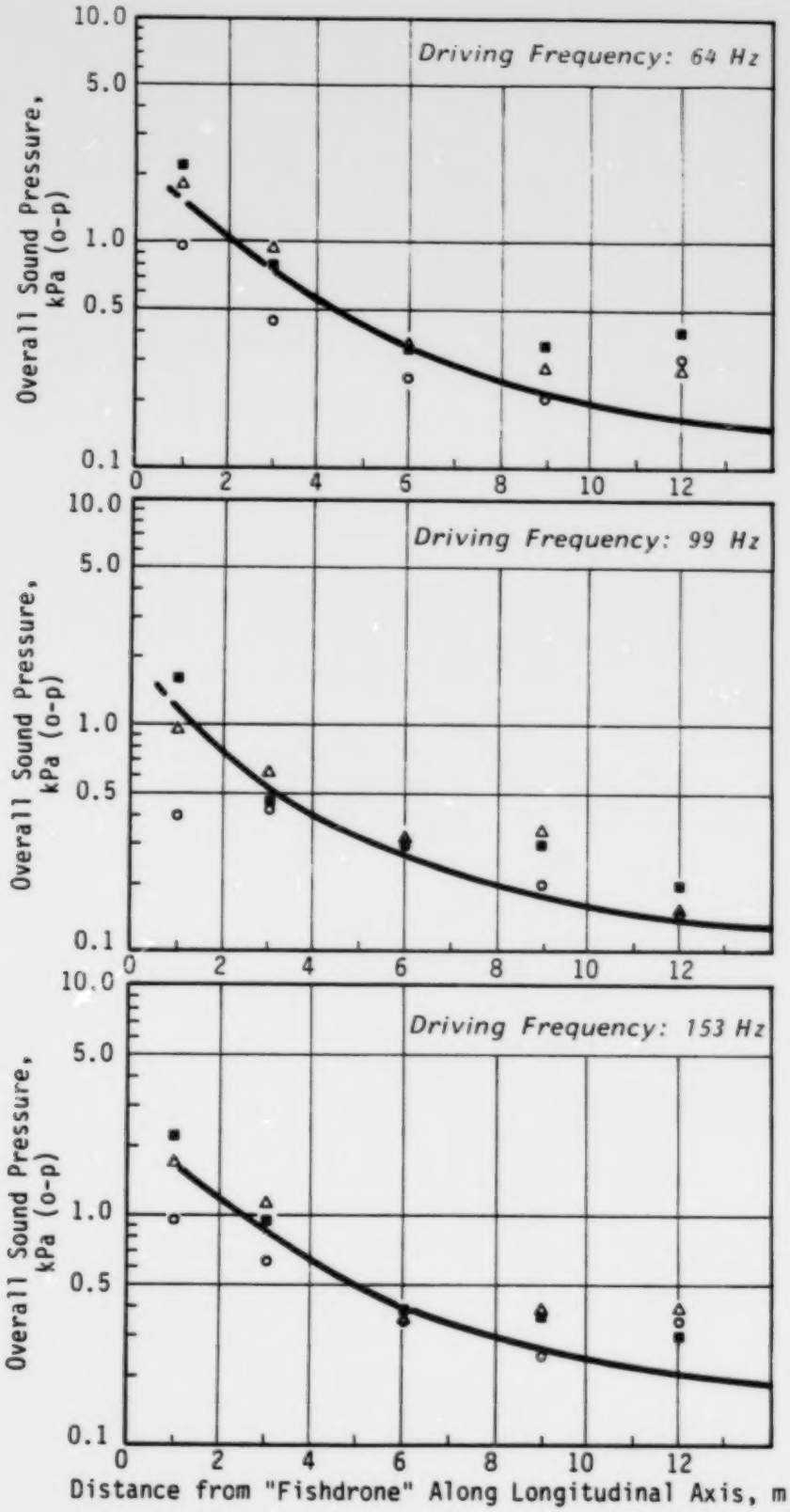


FIGURE 9

SOUND PRESSURE ENVELOPE PRODUCED BY "FISHDRONE" - MODE OF OPERATION: 3 SEC BURST PER4 SEC INTERVAL



— spherical divergence

FIGURE 10

STEADY SOUND PRESSURE PRODUCED BY THE "FISHDRONE" NO. D3 WITH DISTANCE - DEPTH OF FISHDRONE: 2.0 m; DEPTH OF HYDROPHONE: ○- 1.0 m, ■- 2.0 m, △- 3.0 m

171040 RD

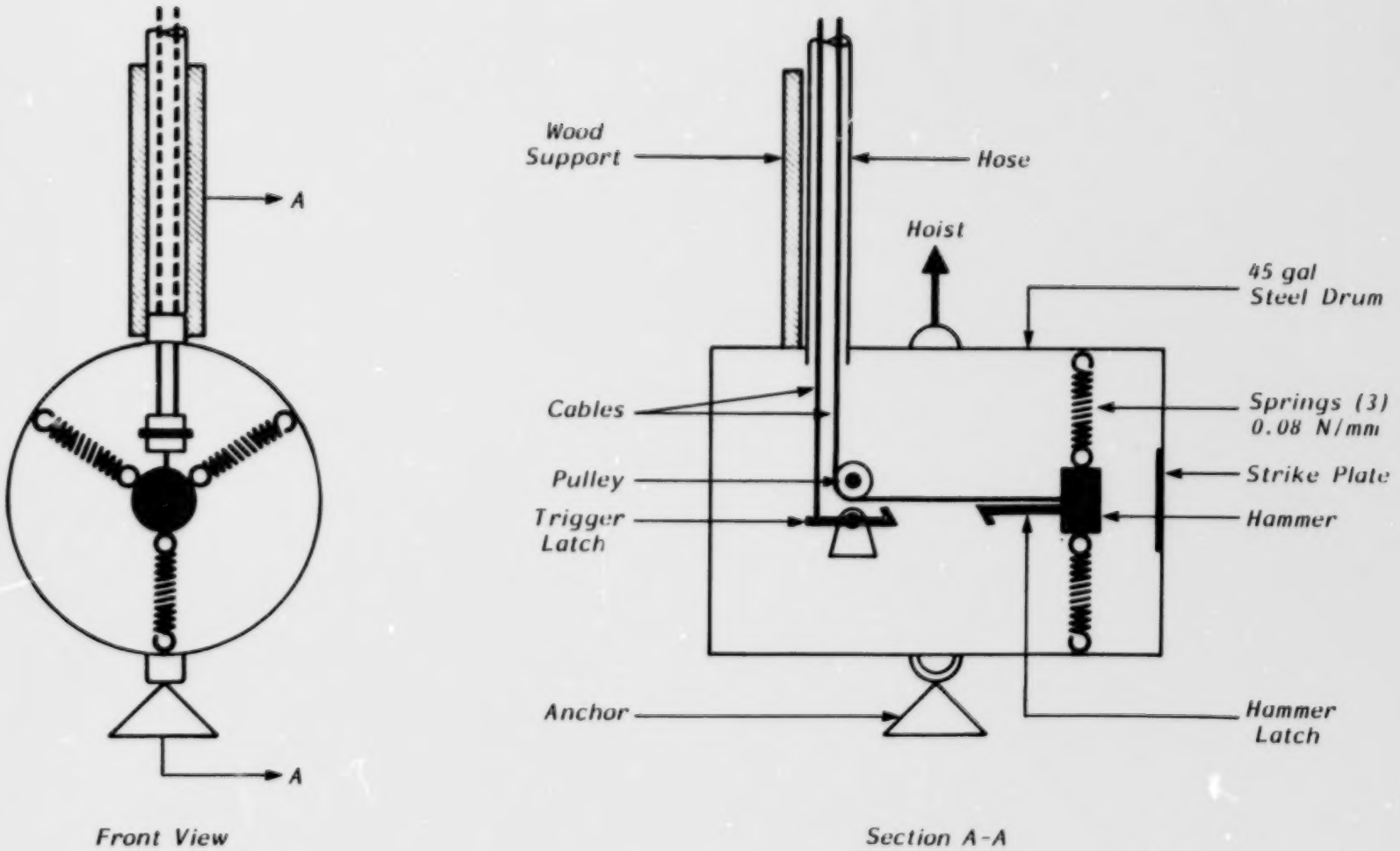


FIGURE 11

SCHEMATIC OF "FISHPULSER" NO.P2
- EXPERIMENTAL UNIT USED IN LABORATORY TESTS

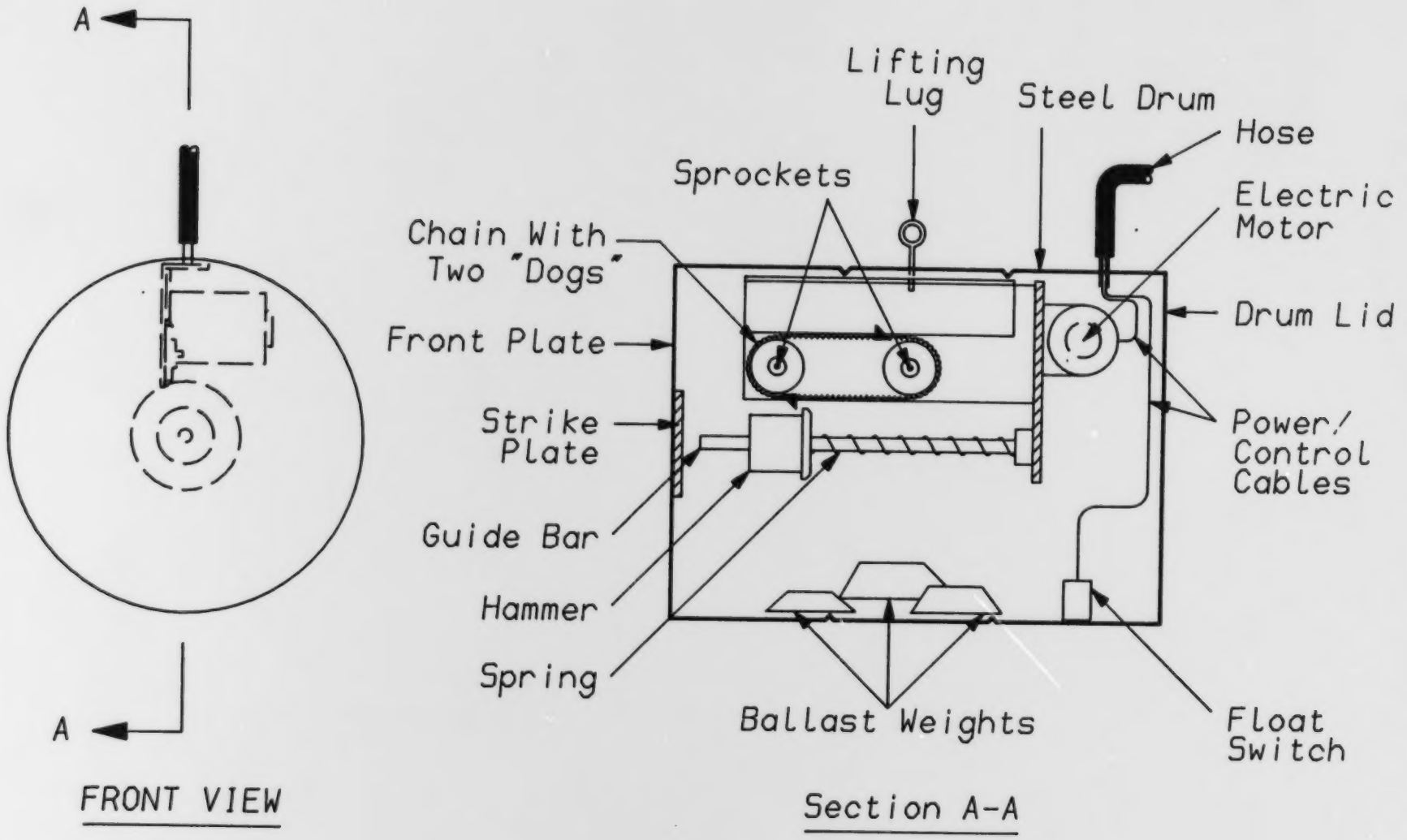


FIGURE 12

SCHEMATIC OF "FISH PULSER" NO P3 TO P7
EXPERIMENTAL UNIT USED IN FIELD TESTS

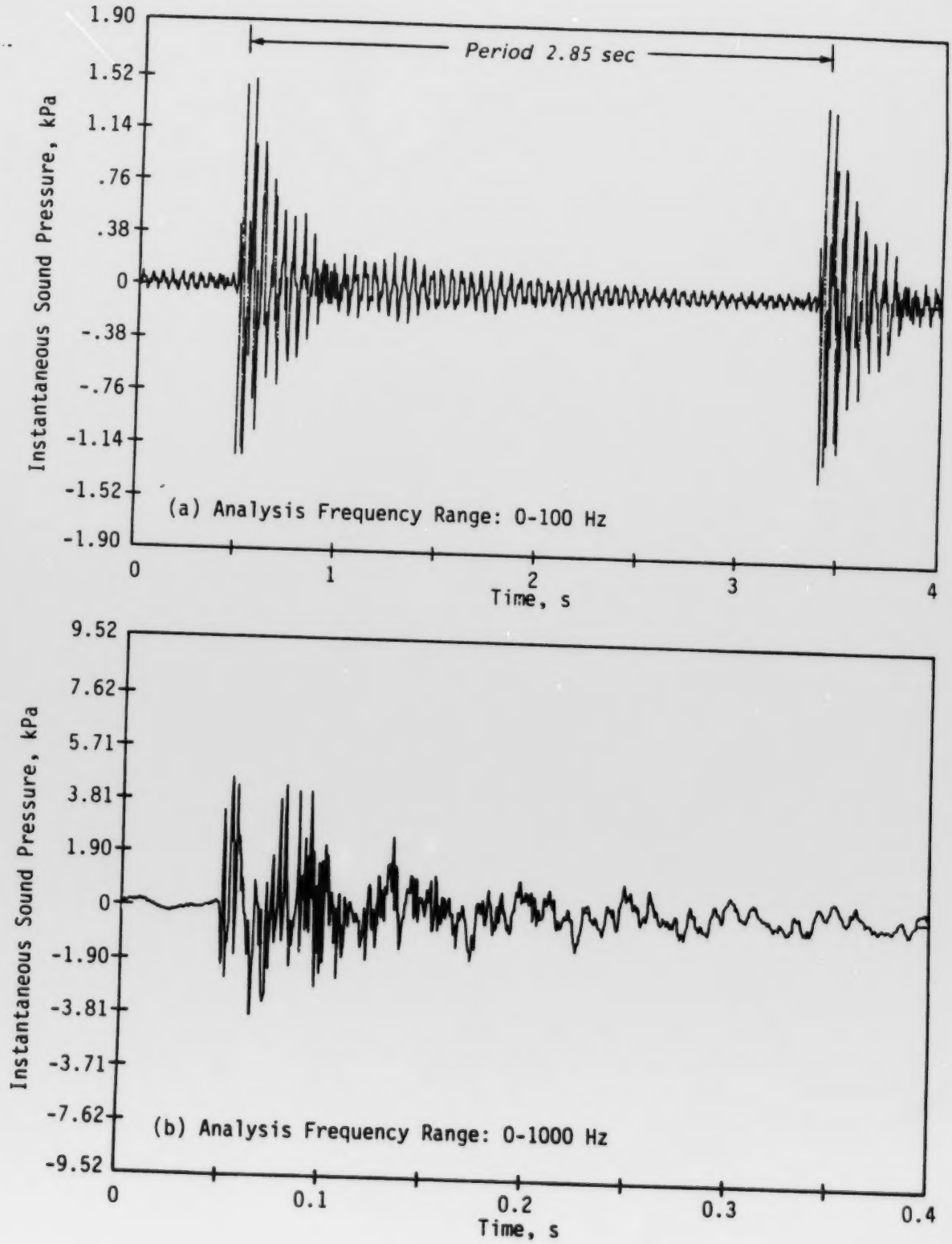


FIGURE 13
TIME HISTORIES OF UNDERWATER ACOUSTIC SIGNALS
AT 1m FROM FISHPULSER NO. P7

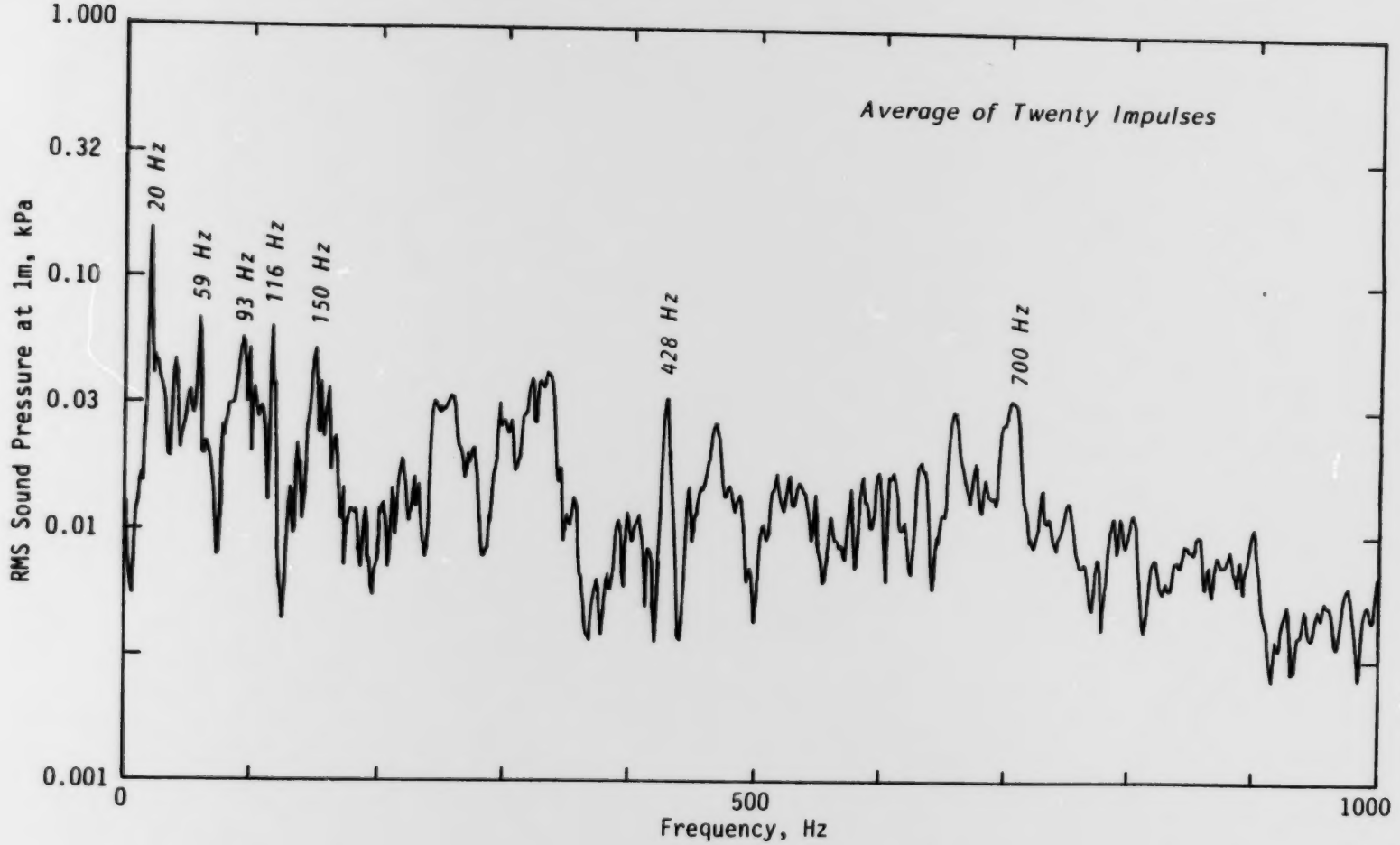


FIGURE 14

UNDERWATER SOUND SPECTRUM AT 1m FROM FISHPULSER NO. P7
MEASURED AT LENNOX TEST FACILITY DEPTH OF DEVICE AND HYDROPHONE 1m

171038 RD

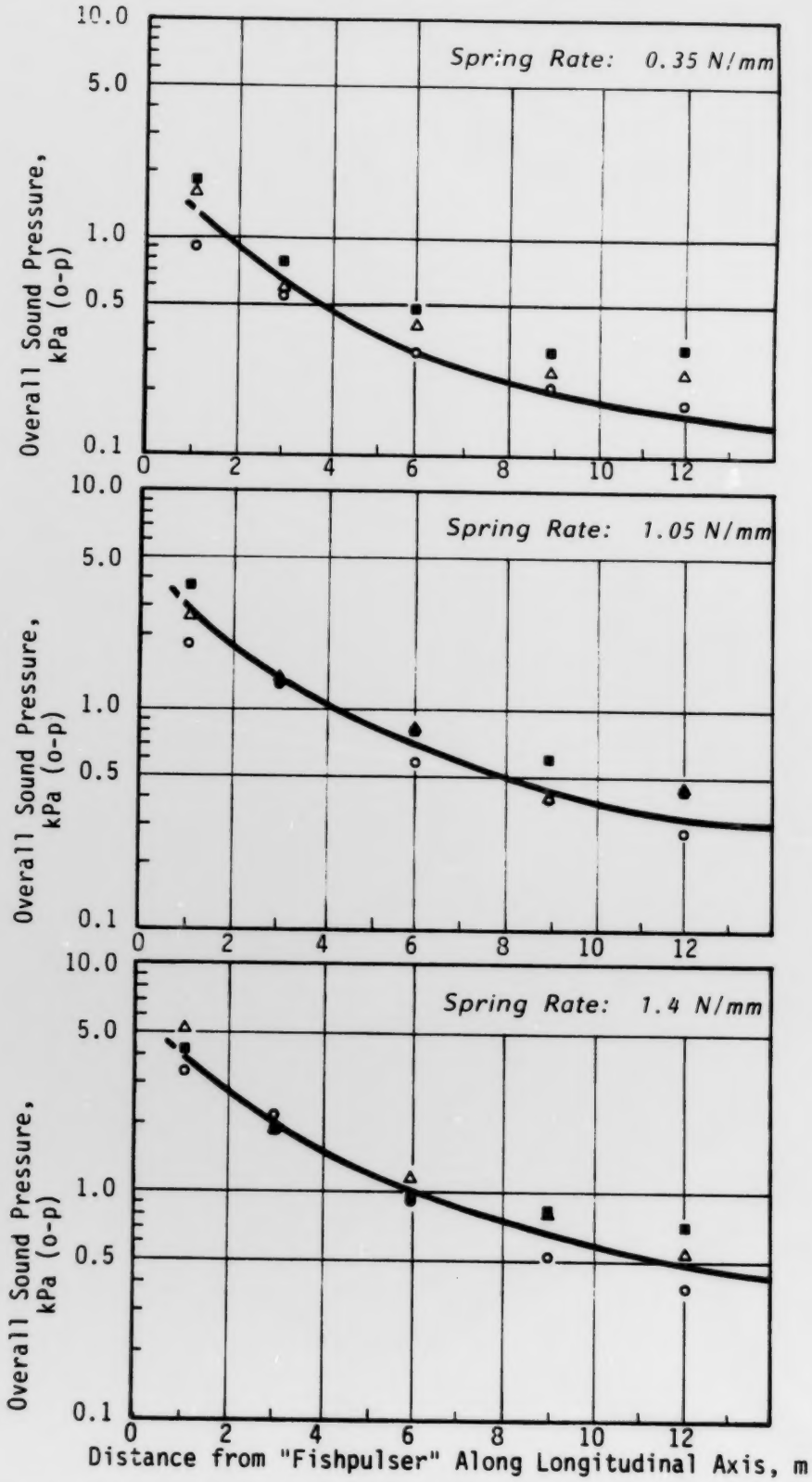


FIGURE 15

IMPULSIVE SOUND PRESSURE PRODUCED BY THE "FISHPULSER" NO. P4 WITH DISTANCE - DEPTH OF HAMMER: 2.0 m; DEPTH OF HYDROPHONE: o- 1.0 m, ■- 2.0 m, △- 3.0 m

171041 RD